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# A BEHAVIORAL ECONOMIC ANALYSIS OF CONCURRENTLY AVAILABLE MONEY AND CIGARETTES

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In economic terms, consumption of a reinforcer is determined by its price and the availability and price of other reinforcers. This study examined the effects of response-requirement (i.e., price) manipulations on the self-administration of two concurrently available reinforcers. Six cigarette smokers participated in 4-hr sessions in which money and puffs on a cigarette were concurrently available according to fixed-ratio schedules of reinforcement. Once stable responding was obtained with both reinforcers available at Fixed Ratio 100, the response requirement for one reinforcer was systematically varied (Fixed Ratio 1,000 and 2,500), while the other reinforcer remained scheduled at Fixed Ratio 100. Increasing the fixed-ratio size for a reinforcer decreased its consumption, with a greater decrease occurring for monetary reinforcement. This finding was quantified in economic terms as own-price elasticity, with elasticity coefficients greater for money than cigarettes. The effects of fixed-ratio size on response output also differed across the two reinforcers. Although greater responding occurred for money at Fixed Ratio 100, increases in fixed-ratio size (for money) *decreased* responding for money, whereas the same increase in fixed-ratio size (for puffs) *increased* responding for puffs. Finally, increasing the fixed-ratio size for one reinforcer had little effect on consumption of the other concurrently available reinforcer. This finding was quantified as cross-price elasticity, with elasticity coefficients near 0.0 for most subjects, indicating little or no reinforcer interaction. The results indicate that the reinforcing effects of cigarettes and money in the setting studied here differed, and that the effects produced by changing the price of one reinforcer did not interact with the consumption of the other concurrently available reinforcer.

*Key words:* behavioral economics, choice, cigarette smoking, demand, drug dependence, elasticity, money, fixed-ratio schedule, humans

Drug dependence can be defined as a behavioral pattern in which drug use has attained a significantly greater degree of control over behavior than other potential reinforcers (see Jaffe, 1990). Because drug reinforcers compete with economic, family, health, and social reinforcers, understanding drug dependence requires identifying factors that render drug taking dominant among these otherwise powerful events (Vuchinich & Tucker, 1988). Discussed in this manner, drug dependence becomes an issue of understanding choice behavior; that is, what factors result in the choice of drugs over other reinforcers (Bickel, Hughes, DeGrandpre, Higgins, & Rizutto, 1992)?

Considerable laboratory research has focused on choice between drug reinforcers and between drug and nondrug reinforcers. Under these procedures, two or more reinforcers are concurrently available such that responding on one manipulandum is maintained by drug reinforcement while responding on another manipulandum is maintained by either a different dose of the same drug, a different drug, or a nondrug reinforcer. In rhesus monkeys, one study examined the effects of intravenous (IV) methylphenidate dose on responding maintained by it and one of two doses of IV cocaine (Johanson & Schuster, 1975). Preference for cocaine decreased as the comparison dose of methylphenidate increased, suggesting that the effectiveness of a reinforcer may vary as a function of its dose and the dose of other available drugs.

Using similar procedures, other researchers have shown effects on choice between a drug and nondrug reinforcer. One study examining discrete choices between food and IV heroin in baboons showed that during baseline conditions, subjects chose, in an alternating fashion, an approximately equal number of heroin and food reinforcers (Griffiths, Wurster, & Brady, 1981). As heroin dose increased, heroin choices *decreased* and food choices increased. These data suggest that as the dose of heroin increased, fewer choices were required to ob-

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tain the same or greater amount of drug, allowing for greater number of food choices. These data differ, however, from data from other studies on choice between drug and nondrug reinforcers. For example, another study showed that choices of IV cocaine by rhesus monkeys significantly *increased* as cocaine dose increased, and decreased as the magnitude of an alternative reinforcer (banana food pellets) increased (Nader & Woolverton, 1991; for a discussion of these differences, see DeGrandpre, Bickel, Hughes, Layng, & Badger, 1993). Overall, these and numerous other studies have shown the utility of choice procedures for examining interactions between reinforcers and for making comparisons of the relative reinforcing effectiveness of pharmacological and nonpharmacological substances (see Katz, 1990).

Recently, behavioral economics has been applied to the study of choice because its unique concepts, methods, and terminology permit quantification of the effects of, and interaction between, qualitatively different reinforcers (Bickel, Hughes, DeGrandpre, Higgins, & Rizutto, 1992; DeGrandpre & Bickel, in press; DeGrandpre, Bickel, Rizvi, & Hughes, 1993; Hursh, 1980; Nader & Woolverton, 1992; Woolverton, 1992). Behavioral economics predicts that choice of a reinforcer is largely determined by the cost to obtain the reinforcer and the presence of other reinforcers (Bickel, DeGrandpre, Higgins, & Hughes, 1990; Bickel, Hughes, DeGrandpre, Higgins, & Rizutto, 1992; Vuchinich & Tucker, 1988).

A basic principle of behavioral economics is the *demand law,* which states that consumption decreases as price increases (Allison, 1983). This law is consistent with the effects of response requirement on drug self-administration; that is, drug consumption decreases as response requirement increases (Griffiths, Bigelow, & Henningfield, 1980; Young & Herling, 1986). The effects of price on the consumption of a reinforcer can be quantified in terms of *own-price elasticity* (Hursh & Bauman, 1987; Samuelson & Nordhaus, 1985). Own-price elasticity measures the proportional change in consumption across different price conditions; on log coordinates, proportional change is equal to the slope of the line. The greater the extent to which an increase in price decreases consumption, the greater the elasticity. Inelastic consumption is defined by elasticities greater than $-1.0$ (Hursh, 1980). Elastic consumption is defined by elasticities less than $-1.0$ (i.e., steeper slope); perfect inelasticity (insensitivity to cost) is defined by an elasticity of 0.0 (Hursh, 1980).

Consider a study that examined (separately) the effects of fixed-ratio (FR) value on IV pentobarbital and IV cocaine self-administration in rhesus monkeys (Goldberg, Hoffmeister, Schlichting, & Wuttke, 1971). Although consumption at FR 1 was similar across the two drugs, increasing the FR decreased consumption more for pentobarbital than for cocaine. When reanalyzed (Bickel, Hughes, DeGrandpre, Higgins, & Rizutto, 1992), pentobarbital's own-price elasticity coefficient was $-0.64$, whereas cocaine's own-price elasticity coefficient was only $-0.05$.

The interaction between different reinforcers can be quantified as a continuum in terms of *cross-price elasticity* (Hursh & Bauman, 1987). At one end of this continuum, reinforcers are *substitutes*; as the price of one reinforcer (e.g., preferred brand of cigarette) increases and its consumption decreases, consumption of a second reinforcer (e.g., generic brand of cigarette)—the substitute—increases. The data of Nader and Woolverton (1991) showing *increases* in food choices as cocaine dose decreased (i.e., unit price for cocaine increased and cocaine consumption decreased) suggest that food was functioning as a substitute under those conditions. Cross-price elasticities greater than 0.0 (positive slopes) indicate a substitute (Hursh & Bauman, 1987). At the other end of the continuum, reinforcers are *complements*; as the price of one reinforcer (e.g., cigarettes) increases and its consumption decreases, the consumption of a second reinforcer (e.g., coffee)—the complement—also decreases. The data reported by Griffiths et al. (1981) showing decreases in food choices as heroin dose decreased (i.e., unit price for heroin increased and heroin consumption decreased) are indicative of complements. Complements have cross-price elasticities less than 0.0 (negative slopes). Between these extremes are *independent* reinforcers; as the cost of one reinforcer (e.g., cigarettes) increases and its consumption tends to decrease, the consumption of a second reinforcer (e.g., alcohol) remains unchanged. Independent reinforcers have elasticities near 0.0.

Reinforcer interactions were also illustrated in a study in which rats had concurrent access to oral ethanol and sucrose solutions (Samson & Lindberg, 1984). Increasing the FR for one reinforcer (sucrose) from 8 to 64 doubled consumption of the other (ethanol). When reanalyzed, a cross-price elasticity of 0.5 was obtained, indicating a "substitutable" interaction (Bickel, Hughes, DeGrandpre, Higgins, & Rizutto, 1992). Similar interactions have been obtained with other drug self-administration studies (e.g., see Bickel, DeGrandpre, Higgins, & Hughes, 1992; Carroll, 1993; Vuchinich & Tucker, 1988). In contrast, however, Griffiths, Bigelow, and Leibson (1976) found that increased alcohol availability *increased* cigarette consumption, indicating a complementary interaction.

We have prospectively applied the behavioral economic conceptualization of own-price and cross-price elasticities to the study of concurrent nicotine (cigarette) and caffeine (coffee) self-administration in humans (Bickel, Hughes, DeGrandpre, Higgins, & Rizutto, 1992). That study reported similar and robust effects of own-price on consumption of the two reinforcers. However, an asymmetrical cross-price effect was found. Price of cigarette puffs was negatively correlated with coffee consumption (i.e., as price of puffs increased, coffee consumption decreased), but price of coffee was not correlated with the concurrent cigarette consumption (i.e., asymmetrical complements).

In the present study, we applied the same conceptualization and procedure used in the coffee and cigarette study (Bickel, Hughes, DeGrandpre, Higgins, & Rizutto, 1992) to examine the effects of response requirement on, and interaction between, concurrently available money and cigarettes. The purpose of this study was threefold. First, we assessed the effects of increasing FR separately on responding maintained by cigarette and money within subjects. In economic terms, this consists of a comparison of the own-price elasticity for two reinforcers within and across individual subjects. This provided a comparison of the relative reinforcing value of a drug and nondrug reinforcer in a laboratory context. Although a behavioral economic analysis of the effects of FR on cigarette consumption has been investigated, such an analysis, to our knowledge, has not been conducted for money reinforcement (however, see Perkins, Epstein, Grobe, & Fonte, 1994). Second, we assessed the effects of increasing the FR to obtain one reinforcer on consumption of the other. This permits an examination of the interaction between money and cigarettes and whether they function as substitutes, complements, or independents in our laboratory context (i.e., a cross-price analysis of reinforcer interaction). To our knowledge, the interaction between a drug and nondrug reinforcer has not been examined prospectively in a behavioral economic framework. Third, comparing these two reinforcers should contribute to research on laboratory models examining how nondrug reinforcers can interact in a choice situation with drug reinforcers.

Cigarette smoking was selected as a convenient form of drug taking to study because cigarette smokers are readily available as subjects, studies of cigarette smoking pertain to other drugs of dependence (because nicotine dependence shares many of the characteristic features of other drugs of dependence; Henningfield & Goldberg, 1983), and cigarette smoking is important to study in its own right because it is a highly prevalent public health problem (Schelling, 1992).

## METHOD

### *Subjects and Apparatus*

Two female and four male cigarette smokers participated in the study. Subjects ranged from 18 to 48 years of age and reported that they smoked from 20 to 25 cigarettes per day (0.7 to 1.2 mg nicotine). Subjects were recruited from newspaper advertisements, were in good health, and reported no medication usage or drug or alcohol abuse other than nicotine. Table 1 lists other relevant characteristics of the subjects.

An Apple IIe® microcomputer controlled and obtained data from a response console (61 cm by 30 cm by 46.5 cm) that contained three Lindsley plungers (Gerbrands No. G6310; centered from left to right on the face of the response console). Subjects responded on the left and right plungers only. Responses made on the center manipulandum produced no programmed effect. Sessions were conducted in rooms that contained two response consoles, overhead fluorescent lighting, and several current magazines. Subjects were provided with their preferred brands of cigarettes. Subjects

Table 1
Subject characteristics.

| Subject | Age | Brand | Nicotine yield[a] | Cigarettes per day |
|---|---|---|---|---|
| BO (female) | 27 | Vantage® | 0.70 | 20 |
| JH (female) | 18 | Camel® filters | 1.00 | 20 |
| JL (male) | 48 | Marlboro® | 1.20 | 20 |
| JP (male) | 36 | Marlboro® | 1.20 | 25 |
| KM (male) | 20 | Camel® filters | 1.00 | 20 |
| PL (male) | 22 | Camel® filters | 1.00 | 20–25 |

[a] Based upon Federal Trade Commission (FTC) estimates of nicotine (mg) per cigarette.

were told not to talk with the other subject (if present) during the experimental session, and each subject's computer screen was out of the visual field of the other subject.

*Procedure*

Four subjects participated in 10 sessions after completing four to seven baseline sessions, and 2 subjects completed six sessions after completing one or two baseline sessions (see Appendix for sequence of conditions for each subject). A minimum of 48 hr elapsed between any two consecutive sessions. Subjects arrived at 7:30 a.m. and were initially given two puffs on a cigarette to equate time from the last cigarette smoked. Sessions began 30 min later. Cigarettes and money were available for a total of 4 hr according to a concurrent FR/FR schedule of reinforcement; subjects were told that if they wished to respond for the cigarettes or money, they could do so ad libitum, but could respond for only one at a time (i.e., subjects could not switch from one lever to the other after initiating a fixed ratio on one lever). Also, subjects were instructed that they had to consume the cigarette puffs during the 3-min signaled intertrial interval (ITI) that followed the completion of the FR for both puffs and money. Subjects received two puffs (except Subject JL, who received one puff) per self-administration of cigarettes and \$0.05, \$0.07, \$0.10, or \$0.20 per money delivery (see Appendix); amount of money per reinforcement was adjusted if necessary after the first baseline session in order to produce an approximately even distribution of responding across the two reinforcers.

The study was conducted in two phases. During the baseline phase, money and cigarettes were available under an FR 100/FR 100 schedule of reinforcement. Subjects remained in the baseline phase until consumption of both substances showed no increasing or decreasing trends across three consecutive sessions (except Subjects JP and PL). Once stability was obtained, the second phase of the study began, in which the FR parameter was manipulated across sessions for one reinforcer while the other reinforcer was available at FR 100. Manipulations consisted of increasing the FR from 100 to 1,000 and 2,500. Each FR parameter was in effect for two nonconsecutive sessions (one session for Subjects JP and PL) and the sequence of the FR values and the reinforcer to which it pertained were ordered quasi-randomly (see Appendix). The response requirements were listed on a sheet of paper provided to subjects at the outset of each session.

Upon completion of the FR, subjects puffed twice on a freshly lit cigarette during a 3-min ITI. Subjects were instructed to light their brand of cigarette without inhaling. Subjects then took one large uniform puff, inhaled, and held for a 5-s period, at which time they were told to exhale. After 25 s, a second puff was taken in an identical fashion (Griffiths, Henningfield, & Bigelow, 1982). After the completion of the FR for money, the amount earned was added to the session total shown on the computer monitor.

*Data analysis.* The number of FRs completed for puffs and money, and the overall response output on each of the two levers, were collected by the computer. These data were analyzed in terms of own-price elasticity of demand ($E_{\mathrm{OWN}}$) using the following equation derived from Allison (1983):

$$E_{\mathrm{OWN}}{}^{\mathrm{A}} = \log(Q_{\mathrm{A2}}) - \log(Q_{\mathrm{A1}})/\log(P_{\mathrm{A2}}) - \log(P_{\mathrm{A1}}),$$

where $Q$ is the quantity consumed of Reinforcer A at price ($P$) 1 or 2 (cf. Bickel, Hughes, DeGrandpre, Higgins, & Rizutto, 1992).[1] Again, using this equation, elasticities (or slopes

[1] Bickel, Hughes, DeGrandpre, Higgins, and Rizutto (1992) used an elasticity formula taken from Samuelson and Nordhaus (1985) that produces only positive elasticity values. In this paper, we use an equation reported by Allison (1983), in which positive elasticities represent positive slopes and negative elasticities represent negative slopes. The latter equation is more consistent with the economic analyses of interactions between reinforcers (see Allison, 1983).

on log coordinates) greater than −1.0 (e.g., −0.1) are indicative of inelastic consumption (not sensitive to price), whereas values below −1.0 (e.g., −10.0) are indicative of elastic consumption (sensitive to price). Elasticity was calculated for each change in FR value (i.e., point elasticities) because broad changes in price usually result in mixed elasticities (Hursh & Bauman, 1987). Hence, averaging across mixed elasticities would be less precise.

Cross-price elasticity, which measures the effects of changes in FR of one reinforcer on consumption of another, was determined for the data as described by Allison (1983). Cross-price elasticity of demand ($E_{\mathrm{CROSS}}$) was defined as follows:

$$E_{\mathrm{CROSS}}{}^{\mathrm{A}} = \log(Q_{\mathrm{A2}}) - \log(Q_{\mathrm{A1}})/\log(P_{\mathrm{B2}}) - \log(P_{\mathrm{B1}}),$$

where $Q$ is the quantity consumed of Reinforcer A at price B1 or B2 (i.e., two prices for Reinforcer B). Positive cross-price elasticity values (i.e., positive slopes on log coordinates) indicate that as price of Reinforcer B increases, consumption of Reinforcer A increases (substitute). Negative cross-price elasticity values indicate that as price of Reinforcer B increases, consumption of Reinforcer A decreases (complement). Values of zero or near zero indicate that increases in Reinforcer B have little or no effect on consumption of Reinforcer A (independent reinforcers). Cross-price elasticity was calculated for each change in FR value.

## RESULTS

Cigarette-puff and money consumption is shown in Figure 1 as a function of the FR for puffs (left panel) and money (right panel). Consumption during the concurrent FR 100/FR 100 condition ranged across subjects from 9 to 32 puffs and from $0.73 to $9.00 (these data are shown twice; i.e., FR 100 condition in both panels). Increasing the FR from 100 to 1,000 for a reinforcer decreased its consumption. However, as indicated by the own-price elasticity coefficients, this increase in response requirement had a relatively greater effect on money than on puffs. Own-price elasticities for the puff manipulation were very similar for 5 of the 6 subjects (excluding Subject PL), varying from −0.23 to −0.40. Own-price elasticities for the money manipulation were also very similar for 5 of the 6 subjects, varying from −1.19 to −1.94 (excluding Subject BO). A further increase in FR from 1,000 to 2,500 produced further decreases in money earnings for those subjects who were not at 0.0 consumption at FR 1,000 (except JP; right panel), although the own-price elasticities were more variable.

The effects of the FR for one reinforcer on the consumption of the other reinforcer (i.e., cross-price elasticity) were small and variable. Increasing the FR for puffs produced a significant increase in consumption of money in only 1 subject (BO). Similarly, increasing the FR for money produced a significant increase in consumption of puffs in only 2 subjects (JH and JP). Thus, a decrease in consumption of one reinforcer (when its FR increased) did not necessarily translate into an increase in consumption of the other reinforcer, even though both maintained responding at FR 100.

The 4 subjects who completed each condition twice (BO, JH, KM, JL) showed little or no variability in either puff or money consumption at each condition, except in one condition for BO and KM.

Response output of both reinforcers is shown as a function of the FR for puffs (left panel) and money (right panel) in Figure 2. Note that (a) because response output equals the product of the number of self-administrations and FR, a perfect correlation exists between consumption and response output, and (b) because the FR did not change for the unmanipulated reinforcer, the functions for the unmanipulated reinforcer have the same elasticities and slopes as in Figure 1.

When both reinforcers were available at FR 100, money maintained higher response rates than cigarette puffs did in 5 of 6 subjects (all except BO). When FR for puffs was increased from 100 to 1,000, response output for puffs increased in a similar fashion across all subjects, except PL. A further increase in FR from 1,000 to 2,500, however, produced further increases in response output in only 2 subjects. As FR for money increased from 100 to 1,000, response output for money decreased across all subjects, except BO. A further increase in FR from 1,000 to 2,500 produced further decreases in response output for 3 of the 4 subjects who did not show 0.0 responses at FR 1,000. Two subjects (JP and PL) showed increases in response output with the increase in FR to 2,500; note that these data are for

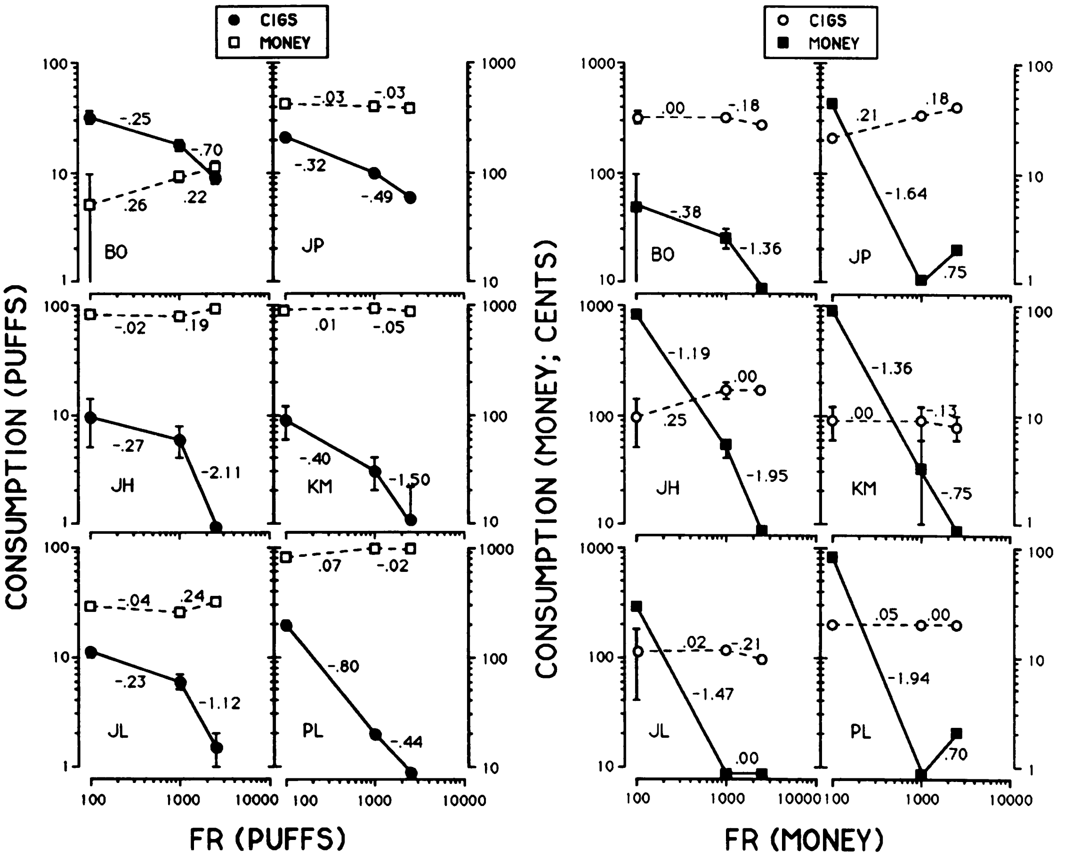


Fig. 1. Cigarette (puffs; circles) and money (cents; squares) consumption is shown as a function of the fixed-ratio response requirement for puffs (left panel) and money (right panel) for the 6 subjects. Data are shown on log coordinates where slope equals elasticity. Data are shown on double axes; the left axes represent values for the reinforcer whose FR was varied, and right axes represent values for the other reinforcer. Own-price and cross-price elasticity coefficients are shown for each change in response requirement. Data points that contact the $x$ axis represent 0.0 consumption. Each data point represents a mean from two sessions, except for Subjects JP and PL, who completed only one session at each condition. Range bars show the range in the data for the 4 subjects who completed each condition twice (all except JP and PL).

the 2 subjects who completed only single sessions in each condition. In terms of the interaction between response output for one reinforcer and the FR for the other reinforcer, these response-output data generally show that within-session response output for one reinforcer was independent of response output for the other reinforcer.

Finally, the relationship between response output for a reinforcer and its FR is plotted for both reinforcers in Figure 3 (solid symbols in Figure 2). This figure provides a clearer illustration of the finding noted above that although response output was greater for money at FR 100, it was considerably more elastic in most subjects.

## DISCUSSION

Money and puffs earned decreased as their FR increased. The magnitude of the decreases in consumption were not comparable across the two reinforcers; money was more elastic than cigarette puffs were. Decreases in consumption of one reinforcer had little effect on the consumption of the other reinforcer, even though both maintained responding at FR 100. And although baseline responding was greater for money than puffs, increases in FR for puffs from FR 100 to 1,000 increased responding for puffs in 5 of 6 subjects, whereas the same increase in FR for money produced decreases in responding for money in 5 of the 6 subjects.

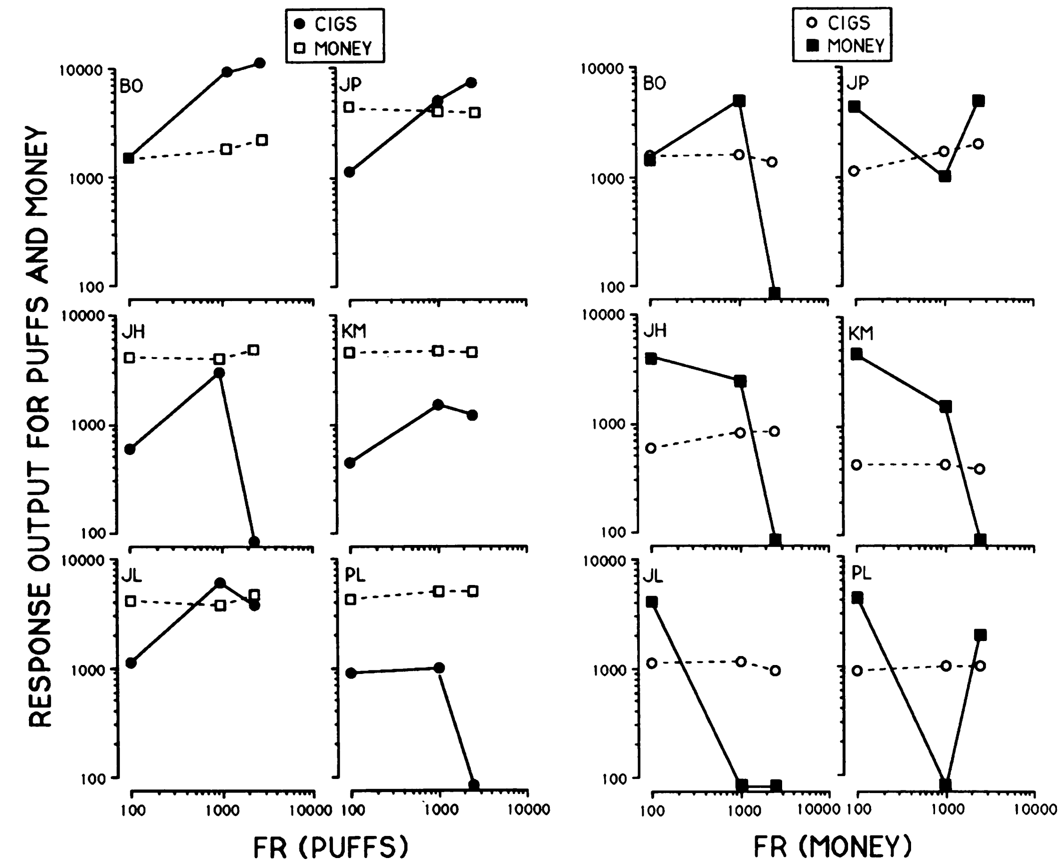


Fig. 2. Response output (total lever operations) for cigarette puffs (circles) and money (squares) is shown as a function of the fixed-ratio response requirement for puffs (left panel) and money (right panel) for the 6 subjects. Data are shown on log coordinates. Data points that contact the *x* axis represent 0.0 responses. Each data point represents a mean from two sessions, except for Subjects JP and PL, who completed only one session at each condition.

The finding that consumption decreased as price (FR) increased is predicted by the demand law (Allison, 1983) and is consistent with several behavioral economic analyses of food-maintained responding (Hursh, Raslear, Shurtleff, Bauman, & Simons, 1988; Lea & Roper, 1977) and more recent behavioral economic analyses of drug self-administration (Bickel et al., 1990; Bickel, DeGrandpre, Hughes, & Higgins, 1991; Bickel, Hughes, DeGrandpre, Higgins, & Rizutto, 1992; DeGrandpre, Bickel, Hughes, & Higgins, 1992). Regarding drug self-administration, the effects of FR on puff consumption in an earlier study (Bickel, Hughes, DeGrandpre, Higgins, & Rizutto, 1992) were quite similar to those reported here (see also Perkins et al., 1994). In the earlier study, the own-price elasticity for puffs when increasing FR from 100 to 1,000 was −0.20 (mean of 8 subjects), whereas in the present study, the elasticity in 5 subjects ranged from −0.20 to −0.40 (excluding Subject PL). Moreover, the shape of the demand curves for puff consumption shown in Figure 1 are highly similar to those reported for other self-administered drugs. This and all other behavioral economic analyses of drug self-administration have reported that drug consumption, plotted on log coordinates, decreases in a positively decelerating fashion (i.e., slope increases with increases in price).

The magnitude of the decreases in consumption was not comparable across the two reinforcers, as indicated by the fact that increases in FR for money did not result in positively decelerating functions for money. Instead, responding for money was considerably more elastic than that for puffs (as indicated

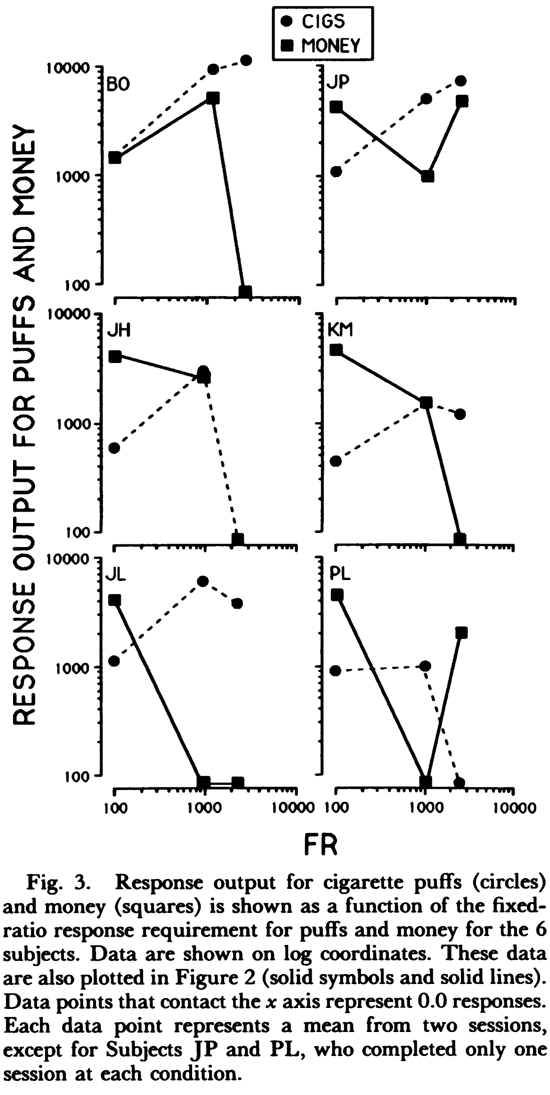


Fig. 3. Response output for cigarette puffs (circles) and money (squares) is shown as a function of the fixed-ratio response requirement for puffs and money for the 6 subjects. Data are shown on log coordinates. These data are also plotted in Figure 2 (solid symbols and solid lines). Data points that contact the $x$ axis represent 0.0 responses. Each data point represents a mean from two sessions, except for Subjects JP and PL, who completed only one session at each condition.

by FR 100 to FR 1,000 elasticity). Subjects' own-price elasticities for money in this study (range, $-1.19$ to $-1.94$, excluding JP) showed greater elasticity than that for coffee in the earlier study ($M = -0.26$). The elasticity of money was also illustrated by the finding that initial increases in FR for puffs (from FR 100 to FR 1,000) increased responding for puffs, whereas the same increase for money produced decreases in responding for money. Note that although money was more elastic, response output was greater for money than for puffs at the lowest price (FR). This result is important because it illustrates the need to examine responding maintained by a stimulus in multiple contexts. If these two reinforcers were assessed at the lowest price only, one might conclude that money is less elastic than puffs and, perhaps, of greater reinforcing value.

Elasticity, like other behavioral effects, is not an inherent "property" of a reinforcer, but rather stems from an interaction of the reinforcer's physical properties with certain environmental, historical, and behavioral variables. Hence, another interpretation of the data for money and cigarette puffs is that money was more elastic than puffs because the relative "price" for money was greater than that for puffs. If the amount of money per response was greater (i.e., lower unit price), money might have been more inelastic and interacted with puff consumption.

The second and third findings concern the interaction between the two reinforcers. Manipulating the price of one reinforcer increased consumption of the other reinforcer in only three cases (money: BO; puffs: JH and HP). In economic terms, these data indicate that one reinforcer functioned as a substitute for the other such that decreases in consumption of one were associated with increases in response output for, and consumption of, the other. Little or no interaction was apparent for the remaining subjects, indicating that the two reinforcers were independent in this context. This independence might have been altered, however, if the FR values differed, amount of money was increased, subjects' deprivation from smoking was increased further, or if the sessions were shortened. That this reinforcer interaction is a function of numerous environmental variables is suggested by the data from Perkins et al. (1994) in which an interaction was shown between money and cigarette puffs under a somewhat different procedure. Increases in relatively low response requirements for puffs under a variable-ratio schedule (during brief sessions) produced decreases in responding for puffs and significant increases in responding for money. Determining whether the differences between these two studies are a function of the type of schedule, schedule value, session length, or some mix of variables would require further experimentation. However, the notion that shorter sessions can affect reinforcer interactions was demonstrated in one study that examined whether choice between heroin and food, at constant magnitudes, would vary as a function of ITI (Elsmore, Fletcher, Conrad, & Sodetz, 1980). Even though an equal number of choices for heroin and food occurred at low ITIs, heroin choices decreased considerably more than food choices did as ITI increased (see also DeGrandpre, Bickel, Rizvi, & Hughes, 1993).

A functional analysis of drug taking may be facilitated by the behavioral economic conceptualization of reinforcer interactions. Such analyses, for example, may have some utility for studying those treatments of drug dependence in which patients engage in alternative and often incompatible activities to drug use (e.g., employment) (see Higgins et al., 1993; Higgins, Budney, & Bickel, in press). Behavioral economics provides a way to assess the effects of nondrug reinforcers on drug-taking behavior and a way to program them to obtain effective therapeutic outcomes. For example, therapeutic programs may promote drug abstinence by providing substitutes and by promoting avoidance of certain activities that serve as complements to drug taking (e.g., association with drug-using friends).

In summary, the present study illustrates the utility of behavioral economics for investigating the reinforcing effects of drugs and the interactions between concurrently available (and nonidentical) reinforcers. As noted by Hursh (1984), behavioral economics provides a measure of reinforcement—elasticity—that is different than other measures of reinforcing value (e.g., the amount of reinforcement or response rate). Also, the cross-price elasticity measure provides a means to quantify the type and degree of interaction between two drugs of abuse (Bickel, DeGrandpre, Higgins, & Hughes, 1992). In the present study, the behavioral economic measure of elasticity (own-price and cross-price elasticity) was effective in quantifying the effects of a response cost of one reinforcer on that reinforcer and on another available reinforcer. The positively decelerating function measured by the own-price elasticities also suggests an interesting empirical tool for evaluating such problems as the process of drug dependence, reinforcer efficacy across different drug reinforcers, individual differences in drug taking and drug seeking, and the effects of pharmacotherapies on drug demand.

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# APPENDIX

| Subject | Session | FR | | | Consumption | | Response output | |
|---|---|---|---|---|---|---|---|---|
| | | Money/Puffs[a] | Money | Puffs | Money | Puffs | Money | Puffs |
| BO | 1 | 100/100 | 0.10 | 2 | 3.20 | 26 | 3,200 | 1,300 |
| | 2 | 100/100 | 0.05 | 2 | 1.70 | 28 | 3,400 | 1,400 |
| | 3 | 100/100 | 0.05 | 2 | 1.55 | 26 | 3,100 | 1,300 |
| | 4 | 100/100 | 0.05 | 2 | 1.45 | 28 | 2,900 | 1,400 |
| | 5 | 100/100 | 0.05 | 2 | 1.10 | 26 | 2,200 | 1,300 |
| | 6 | 100/100 | 0.05 | 2 | 1.25 | 26 | 2,500 | 1,300 |
| | 7 | 100/100 | 0.05 | 2 | 1.65 | 34 | 3,300 | 1,700 |
| | 8 | 100/2,500 | 0.05 | 2 | 1.25 | 8 | 2,500 | 10,000 |
| | 9 | 1,000/100 | 0.05 | 2 | 0.20 | 30 | 400 | 1,500 |
| | 10 | 100/1,000 | 0.05 | 2 | 1.00 | 20 | 2,000 | 10,000 |
| | 11 | 2,500/100 | 0.05 | 2 | 0.00 | 28 | 0 | 1,400 |
| | 12 | 100/100 | 0.05 | 2 | 0.95 | 36 | 1,900 | 1,800 |
| | 13 | 1,000/100 | 0.05 | 2 | 0.30 | 34 | 6,000 | 1,700 |
| | 14 | 100/2,500 | 0.05 | 2 | 0.95 | 10 | 1,900 | 12,500 |
| | 15 | 100/100 | 0.05 | 2 | 0.50 | 28 | 1,000 | 1,400 |
| | 16 | 100/1,000 | 0.05 | 2 | 0.80 | 16 | 1,600 | 8,000 |
| | 17 | 2,500/100 | 0.05 | 2 | 0.00 | 26 | 0 | 1,300 |
| JL | 1 | 100/100 | 0.15 | 1 | 7.50 | 4 | 5,000 | 400 |
| | 2 | 100/100 | 0.15 | 1 | 7.80 | 5 | 5,200 | 500 |
| | 3 | 100/100 | 0.07 | 1 | 2.38 | 16 | 3,400 | 1,600 |
| | 4 | 100/100 | 0.07 | 1 | 2.52 | 17 | 3,600 | 1,700 |

APPENDIX (*Continued*)

| Subject | Session | FR Money/Puffs[a] | Money | Puffs | Consumption Money | Consumption Puffs | Response output Money | Response output Puffs |
|---|---|---|---|---|---|---|---|---|
| | 5 | 100/100 | 0.07 | 1 | 2.66 | 14 | 3,800 | 1,400 |
| | 6 | 100/1,000 | 0.07 | 1 | 2.38 | 7 | 3,400 | 7,000 |
| | 7 | 2,500/100 | 0.07 | 1 | 0.00 | 10 | 0 | 1,000 |
| | 8 | 1,000/100 | 0.07 | 1 | 0.00 | 14 | 0 | 1,400 |
| | 9 | 100/2,500 | 0.07 | 1 | 3.36 | 1 | 4,800 | 2,500 |
| | 10 | 100/100 | 0.07 | 1 | 2.94 | 10 | 4,200 | 1,000 |
| | 11 | 100/100 | 0.07 | 1 | 2.80 | 12 | 4,000 | 1,200 |
| | 12 | 100/1,000 | 0.07 | 1 | 2.80 | 5 | 4,000 | 5,000 |
| | 13 | 100/2,500 | 0.07 | 1 | 3.08 | 2 | 4,400 | 5,000 |
| | 14 | 2,500/100 | 0.07 | 1 | 0.00 | 9 | 0 | 900 |
| | 15 | 1,000/100 | 0.07 | 1 | 0.00 | 9 | 0 | 900 |
| JP | 1 | 100/100 | 0.10 | 2 | 4.00 | 20 | 4,000 | 1,000 |
| | 2 | 100/100 | 0.10 | 2 | 4.20 | 20 | 4,200 | 1,000 |
| | 3 | 100/100 | 0.10 | 2 | 4.30 | 22 | 4,300 | 1,100 |
| | 4 | 100/1,000 | 0.10 | 2 | 4.00 | 10 | 4,000 | 5,000 |
| | 5 | 2,500/100 | 0.10 | 2 | 0.20 | 40 | 5,000 | 2,000 |
| | 6 | 100/2,500 | 0.10 | 2 | 3.90 | 6 | 3,900 | 7,500 |
| | 7 | 1,000/100 | 0.10 | 2 | 0.10 | 34 | 1,000 | 1,700 |
| KM | 1 | 100/100 | 0.05 | 2 | 0.00 | 14 | 0 | 700 |
| | 2 | 100/100 | 0.20 | 2 | 8.60 | 14 | 4,300 | 700 |
| | 3 | 100/100 | 0.20 | 2 | 9.00 | 14 | 4,500 | 700 |
| | 4 | 100/100 | 0.20 | 2 | 9.00 | 14 | 4,500 | 700 |
| | 5 | 100/100 | 0.20 | 2 | 9.00 | 12 | 4,500 | 600 |
| | 6 | 1,000/100 | 0.20 | 2 | 0.60 | 12 | 3,000 | 600 |
| | 7 | 100/1,000 | 0.20 | 2 | 9.20 | 4 | 4,600 | 2,000 |
| | 8 | 100/2,500 | 0.20 | 2 | 8.60 | 2 | 4,300 | 2,500 |
| | 9 | 2,500/100 | 0.20 | 2 | 0.00 | 10 | 0 | 500 |
| | 10 | 100/2,500 | 0.20 | 2 | 9.20 | 0 | 4,600 | 0 |
| | 11 | 100/100 | 0.20 | 2 | 9.00 | 6 | 4,500 | 300 |
| | 12 | 1,000/100 | 0.20 | 2 | 0.00 | 6 | 0 | 300 |
| | 13 | 100/1,000 | 0.20 | 2 | 9.40 | 2 | 4,700 | 1,000 |
| | 14 | 2,500/100 | 0.20 | 2 | 0.00 | 6 | 0 | 300 |
| PL | 1 | 100/100 | 0.20 | 2 | 7.80 | 22 | 3,900 | 1,100 |
| | 2 | 100/100 | 0.20 | 2 | 8.40 | 22 | 4,200 | 1,100 |
| | 3 | 100/100 | 0.20 | 2 | 8.00 | 22 | 4,000 | 1,100 |
| | 4 | 100/1,000 | 0.20 | 2 | 10.00 | 2 | 5,000 | 1,000 |
| | 5 | 100/2,500 | 0.20 | 2 | 9.80 | 0 | 4,900 | 0 |
| | 6 | 100/100 | 0.20 | 2 | 8.60 | 18 | 4,300 | 900 |
| | 7 | 2,500/100 | 0.20 | 2 | 0.20 | 20 | 2,500 | 1,000 |
| | 8 | 1,000/100 | 0.20 | 2 | 0.00 | 20 | 0 | 1,000 |
| JH | 1 | 100/100 | 0.05 | 2 | 0.00 | 18 | 0 | 900 |
| | 2 | 100/100 | 0.20 | 2 | 7.60 | 14 | 3,800 | 700 |
| | 3 | 100/100 | 0.20 | 2 | 7.00 | 16 | 3,500 | 800 |
| | 4 | 100/100 | 0.20 | 2 | 7.40 | 16 | 3,700 | 800 |
| | 5 | 100/1,000 | 0.20 | 2 | 7.20 | 8 | 3,600 | 4,000 |
| | 6 | 2,500/100 | 0.20 | 2 | 0.00 | 18 | 0 | 900 |
| | 7 | 100/100 | 0.20 | 2 | 7.40 | 14 | 3,700 | 700 |
| | 8 | 100/2,500 | 0.20 | 2 | 9.40 | 0 | 4,700 | 0 |
| | 9 | 1,000/100 | 0.20 | 2 | 0.40 | 14 | 2,000 | 700 |
| | 10 | 2,500/100 | 0.20 | 2 | 0.00 | 16 | 0 | 800 |
| | 11 | 100/2,500 | 0.20 | 2 | 9.60 | 0 | 4,800 | 0 |
| | 12 | 1,000/100 | 0.20 | 2 | 0.60 | 20 | 3,000 | 1,000 |
| | 13 | 100/1,000 | 0.20 | 2 | 8.80 | 4 | 4,400 | 200 |
| | 14 | 100/100 | 0.20 | 2 | 9.20 | 10 | 4,600 | 500 |

[a] Per self-administration.